



Unlined Reusable Filament Wound Composite Cryogenic Tank Testing

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TECHNICAL MEMORANDUM

UNLINED REUSABLE FILAMENT WOUND COMPOSITE CRYOGENIC TANK TESTING

1. INTRODUCTION

Over the past several years, the need for a “faster, better, and cheaper” approach to space access has led to research and development of composite materials suitable for launch and space environments. Several composite bottles (tanks) and ducts have been tested at the Marshall Space Flight Center (MSFC) to verify their compatibilities with cryogenic temperatures and pressures. MSFC has developed a composite testing station at its Test Stand 300 that allows for relatively quick installation and testing of a composite test article. The testing of the Phillips Laboratory/Wilson Composite Group, Inc. composite bottle will be discussed.

2. TEST ARTICLE

The test article was an unlined reusable filament wound composite cryogenic tank made of Fiberite's IM7/977-2 carbon fiber/toughened epoxy with an 18-inch diameter and a 32-inch length. The boss closure flange assemblies were made using Nitronic 60 material. Each flange assembly consisted of two pieces: one over which the composite was wound and one which was bolted to the first flange. Each bolted flange was machined with a 1-inch AN threaded hole. The wall thickness of the tank was measured at 0.084 inches. The weight of the composite portion of the tank was 9 pounds and the total weight was 55 pounds. The tank was designed to burst at 1,800 psig; however, due to a manufacturing defect (a wrinkle in the composite), the testing pressure was lowered to 320 psig. Phillips Laboratory and Wilson Composite Group, Inc. successfully mended the defect in the composite for testing.

3. INSTRUMENTATION

The test article was instrumented by MSFC with 15 strain gauges, four acoustic transducers, and four thermocouples, all located on the outer skin of the tank (see fig. 1). The thermocouples, which indicated the skin temperature, were mounted in four locations: on the bottom dome, 6 inches higher on the barrel, 6 inches higher on the barrel, and on the upper dome.

3.1 Strain Measurement

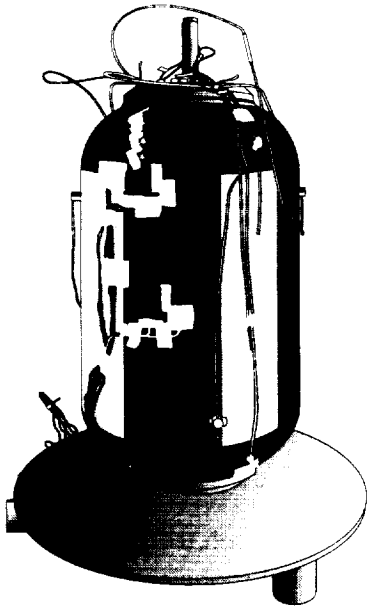


Figure 1. Composite tank configured for testing.

The measurement of strain in composite materials is not unusual. What is unusual is measuring the strain while the composite material is at cryogenic temperatures. Standard practice for measuring strains at cryogenic temperatures is to perform an "apparent strain" test. A coupon (typically 2 inches by 2 inches) of the test material is instrumented with a strain gauge and temperature sensor. The coupon is then subjected to thermal cycles from ambient to the expected cryogenic temperature while the outputs of the strain gauge and temperature sensor are monitored. Any change in output from the strain gauge is an apparent strain, as the strain from the coupon is negligible. The apparent strain value is correlated with the temperature value. On the test article, each strain measurement has an associated temperature measurement. During data reduction, the apparent strain is subtracted from the strain measured during the test to find the actual strain value. Note that all strain gauges must be from the same lot or else an apparent strain test must be performed for each lot.

For the Phillips Laboratory composite tank, no composite material was available for doing a coupon test, so an alternative approach was taken. At each strain measurement location, the strain gauges were mounted in a half-bridge configuration. One gauge measured the strain while the other gauge compensated for the apparent strain. The measuring gauge was bonded to the tank surface, while the compensating gauge was taped to the tank surface. Although this was not the optimal method for measuring strain, no other method was available for this test.

The strain gauges used were designed for use in cryogenic environments. They were not specifically designed for use on composite materials. The gauge backing material was a glass-fiber-reinforced epoxy-phenolic, well suited for use over a wide temperature range. However, the material was rather brittle, limiting elongation to about 1 to 2 percent. Therefore, any highly localized steep strain gradients on the surface of the tank could have resulted in premature failure of the gauge. The gauge length was 0.250 inch with a grid width of 0.125 inch. The large gauge area helped to average out any steep strain gradients.

The tank surface was very coarse with many peaks and valleys. Therefore, a 100 percent solid-filled epoxy was used. The surface area for each gauge was first degreased with isopropyl alcohol, then lightly dry abraded with 320 grit silicon-carbide paper before applying conditioner and neutralizer. Generous amounts of adhesive were applied to fill in the peaks and valleys of the tank surface. A silicone gum pad and a metal backing plate were laid on top of the gauge. This assembly was then taped down with masking tape while the epoxy cured at room temperature overnight. Only a small amount of pressure was used when applying the masking tape. Too much pressure would have squeezed the adhesive out from under the gauge installation, leaving voids. All gauges were then covered with a waterproof coating.

Since the strain gauges were mounted in a half-bridge configuration on the tank surface, the Wheatstone bridge was completed at the signal conditioner located in a block house approximately 200 feet away. The excitation power supplied to the bridge was 1 volt rather than the standard 10 volts. This was done to reduce infrared heating of the strain gauges since composite materials are typically poor thermal conductors. Overheating would change the composite material and strain gauge characteristics, resulting in erroneous strain readings.

3.2 Acoustic Emission Transducers

The purpose for including acoustic emission (AE) monitoring on this tank was to detect and locate AE signals that might indicate structural damage occurring to the vessel. Four AE transducers were bonded to the tank using epoxy. The transducers were attached to the cylindrical region of the tank, near the dome at each end. Two transducers were used at each end, forming a triangular grid around the circumference of the tank. The purpose of the grid was to attempt to locate the sources of acoustic emission.

4. TESTING

4.1 Proof Test

The composite bottle was hydrostatically proof tested to 380 psig for 5 minutes with no anomalies.

4.2 Leak Test

Two methods of leak detection were used: mass spectrometry of gaseous helium (GHe) and liquid soap solution bubble check. The mass spectrometry was used to verify no leakage through the composite wall. The liquid soap solution was used to detect leaks around the flanges.

During initial leak checks of the composite and its flanges, mass spectrometry was used to detect GHe at 50 psig. The composite walls did not leak down to the $1 \text{ by } 10^{-7}$ standard cubic centimeters per minute (scc/min) range before and after cryogenic testing; however, the flange joints (both flange-to-flange and flange-to-composite) leaked and rendered the mass spectrometry method useless at the flanges. The flange bolts were tightened and the joints were leak checked using the liquid soap solution. Although the joint continued to leak "shave cream" type bubbles, the level of leakage was acceptable to proceed with testing and would not compromise the goal of verifying the permeability of the composite.

4.3 Test Setup

The composite bottle was mounted vertically from flange to flange in ambient conditions at the MSFC Test Stand 300 (see fig. 2). The bottle was mounted inside an insulated cylinder which was purged with GHe. A 1-inch fill line was used to supply the cryogen and a 2-inch vent line was used on the outlet. The fill and vent lines were insulated to minimize heat transfer. Variable position valves were used for fill and vent line isolation. Fill and vent thermocouples and pressure transducers were used. The test article was filled from the bottom and vented out the top into a small insulated accumulator and then through the vent line isolation valves and to the burn stack. The accumulator, which was located above the test article, was used to allow the cryogenic liquid to completely fill the test article. The gaseous hydrogen (GH₂) pressurization system entered upstream of the vent valves.

4.4 Test Procedure

The test article, the fill line, and the vent line were purged with gaseous nitrogen (GN₂) for 15 minutes, followed by GH₂ for 15 minutes and five pressurization cycles from 0 psig to 45 psig with GH₂. Data recording was begun for strain gauges, acoustic transducers, thermocouples, and pressure transducers. The trailer valve of the liquid hydrogen (LH₂) trailer, pressurized to 20 psig, was opened to allow LH₂ to flow through the test article and out the burnstack. The flow rate was reduced after liquid

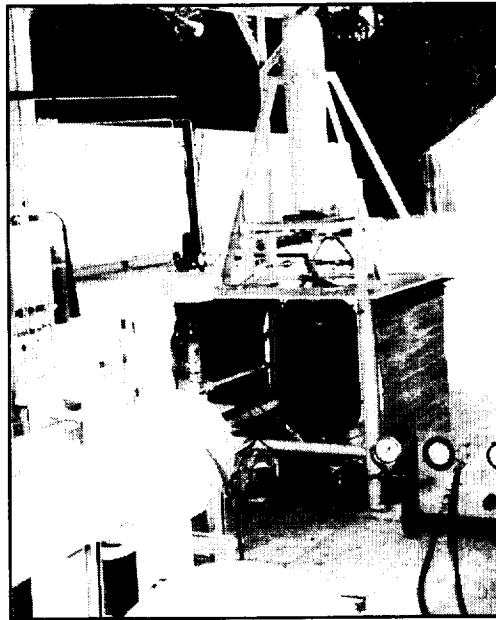


Figure 2. Composite tank set up for testing.

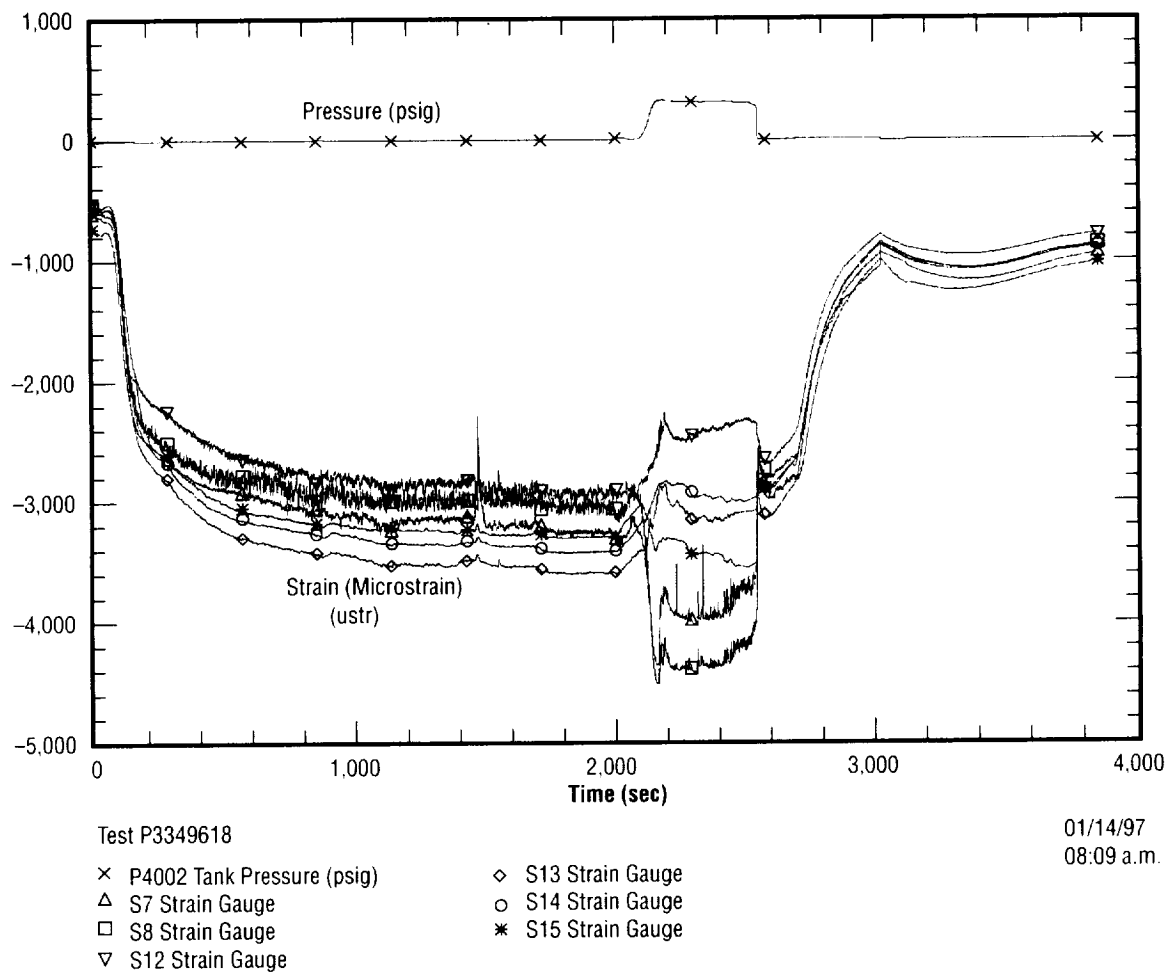


Figure 3. Representative strain gauge output.

was indicated at the test article to allow test article to chill using a minimum amount of LH₂. Once the bottle temperatures stabilized, the fill line valve and the vent line valves were closed. The test article was pressurized to 320 psig for 5 minutes and then vented. The test article was drained to allow test article temperatures to rise to 0 °F. The first test was performed with LN₂ instead of LH₂. Tests 2 through 18 were performed with LH₂.

4.5 Test Results

Eighteen pressurization tests were successfully performed with no anomalies except in data acquisition, which is discussed under 4.4.1 “Strain Measurement”.

After the 18 tests, the test article was tested for permeability. The barrel and dome portions of the test article were isolated from the flanges using a plastic bag and tape. The bag was slowly purged with GN₂ to create a positive pressure. The mass spectrometer detection element was inserted into the bag. GHe was released outside the bag around the taped seals to verify that no outside GHe would be detected within the bag. The test article was then pressurized to 45 psig with GHe to determine if the composite material leaked. No leakage was detected down to the 1 by 10⁻⁷ scc/min range.

4.4.1 Strain Measurement

During the test, the compensating gauges did not adhere adequately to the tank surface. Therefore, the compensating gauges were not at the same temperature as the measuring gauges. This resulted in the apparent strain not being subtracted from the signal. Consequently, all of the strain readings were of little value since they were a combination of the actual strain, apparent strain of the measuring gauge, and the apparent strain of the compensating gauge. A typical output of the strain gauges is shown in figure 3. Post-test inspection showed that the measuring gauges bonded well to the tank surface. The compensating gauges were peeled off the tank surface by the waterproof coating. The air gaps under the gauge and the tape prevented the waterproof coating from adhering to the tank surface after repeated thermal cycles.

4.4.2 Acoustic Emission

Over 3,000 acoustic emission sounds or “hits” were recorded on the first pressurization cycle. Each subsequent cycle consistently produced around 1,000 hits. While the pressure was held at its upper limit, the hit rate as a function of time remained near zero. The absence of hits indicated structural soundness in the tank since degradation of the tank composite material would have been indicated by a continuation of hits at the steady state.

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5. CONCLUSIONS

The composite material tested is compatible with LH_2 to 320 psig, exhibiting no leakage when tested with GHe. The composite-to-metallic interface seal design was inadequate to prevent “bubble” leaks, but proved adequate for the required testing. Further design and testing is needed on composite-to-metallic seals, both in the lay-up of composites on the metallic flange and composite flange-to-metallic flange interfaces.

5.1 Strain Measurement

The use of a taped compensating gauge did not work well. The coarse tank surface allowed air gaps under the compensating gauge, tape, and waterproof coating. During thermal cycling, the tape and waterproof coating lifted the compensating gauge off the tank surface. Even if the tape had worked well, the thermal transfer rates between the tank and the measuring gauge and between the tank and the compensating gauge would have been different simply because the two gauges were attached to the tank surface by two different means. Therefore, conducting an apparent strain test, locating a temperature measurement at each strain gauge location, and subtracting the apparent strain from the data appears still to be the most reliable approach under these test conditions.

5.2 Acoustic Emission

The AE monitoring system worked well and provided the test requestor with valuable data that indicated no structural damage occurred to the tank.